AD-A046 707 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/2
THE CANOL PIPELINE PROJECT. A HISTORICAL REVIEW.(U)
OCT 77 H T UEDA, D E GARFIELD, F D HAYNES
UNCLASSIFIED CRREL-SR-77-34 NL

| OF |

AD
A046707

END
DATE
FILMED
12-77
DDC

SR 77-34

CRREL

(12)

Special Report 77-34

AD A 046707

THE CANOL PIPELINE PROJECT

A Historical Review

H.T. Ueda, D.E. Garfield and F.D. Haynes

October 1977

Prepared for
DIRECTORATE OF FACILITIES ENGINEERING
OFFICE, CHIEF OF ENGINEERS
By
CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (9) Special Re[redacted]t 77-34	2. GOVT ACCESSION NO. (14) CRREL-SR-77-34	3. ~~RECIPIENT'S CATALOG NUMBER~~
4. TITLE (*and Subtitle*) (6) THE CANOL PIPELINE PROJECT. A Historical Review.		5. ~~TYPE OF REPORT & PERIOD~~ COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) (10) H.T./Ueda, D.E./Garfield [redacted] F.D./Haynes		8. CONTRACT OR GRANT NUMBER(*s*) Intra-Army Order No. ENG-CRREL-77-12
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Facilities Engineering Office, Chief of Engineers Washington, DC 20314		12. REPORT DATE (11) Oct[redacted] 1977
		13. NUMBER OF PAGES ~~35~~ (12) 37p.
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Arctic region, North America
Canol Pipeline Project
Pipeline

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This report is a historical review of the Canol project, the first long-distance petroleum pipeline system constructed in the Arctic region of North America. The project was initiated during the early days of World War II when the military situation appeared critical. It was designed to supply the military need for fuel in the area, particularly Alaska, by exploiting the Norman Wells oil field in the Northwest Territory of Canada. The system was completed in April 1944 and operated for 11 months converting 975,764 barrels

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

037100

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

20 (cont'd)

of crude oil into gasoline and fuel oil. Construction for the pioneering effort was difficult and costly. Considerable controversy plagued the project throughout; nevertheless, its completion proved that undertakings of such magnitude could be accomplished despite the formidable problems of the Arctic.

PREFACE

This report was prepared by H.T. Ueda, Mechanical Engineer, and D.E. Garfield, Research Mechanical Engineer of the Engineering Services Branch, Technical Services Division, and F.D. Haynes, Materials Research Engineer of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL).

This study was funded under Intra-Army Order No. ENG-CRREL-77-12, Consolidated Trans-Alaska Pipeline Research Program; task, Surveillance of the Trans-Alaska Pipeline Project; Work Unit, Terminals and Pump Stations.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

CONTENTS

ILLUSTRATIONS

THE CANOL PIPELINE PROJECT

Introduction

The present and the proposed construction of pipelines in Alaska, such as the 48-inch pipeline constructed by Alyeska, has revived some interest in other lines which have been built and operated in the Arctic and Sub-Arctic regions. Most of the earlier efforts were physically dwarfed by the present line and in addition they did not come under today's environmental scrutiny; however, there are still some interesting similarities. These early pipelines proved the feasibility of large scale road construction and pipelaying under extremely difficult conditions. They pioneered the techniques of working with the ever present snow, ice and permafrost. The engineering problems and the harsh environment still prevail but they are no longer as formidable as they once appeared, due in part to these early efforts. This report is a historical investigation of one of those early endeavors; namely, the Canol Pipeline Project.

The Canol* Project was designed to supply crude oil from the Norman Wells oil field in the Northwest Territory, Canada, to a refinery at Whitehorse, Yukon Territory, where fuel could be produced and distributed to the interior of Alaska and to stations on the interior routes to Alaska. It was conceived during the early stages of World War II when the military situation in the North Pacific was critical. Combined with the Alcan Highway**, it was considered to be one of the largest construction programs ever attempted. It was completed in Jan. 1944 amidst a

* Canadian Oil Line
** Canada-Alaska Highway

storm of controversy, since by then the strategic importance of the project no longer existed. Its period of operation was relatively brief; nevertheless it did represent an outstanding construction achievement under the severest conditions of terrain, weather, isolation and construction difficulties and demonstrated that modern equipment with experience and ingenuity could be employed successfully in the Arctic.

History

As far back as 1789 Alexander Mackenzie, in exploring the river valley which now bears his name, discovered oil seeping out of the river bank near what is now Norman Wells, N.W.T., 75 miles (121 km) from the Arctic Circle.

The first well was drilled in 1920 by the Northwest Company, a subsidiary of Imperial Oil Ltd. Oil began seeping into the hole at 85 ft (26 m) and flow was realized at a depth of 783 ft (239 m). The well was eventually deepened to 1025 ft (313 m) and produced an estimated 75-125 bbl* per day. A small refinery still was installed in 1921. A second well reached oil at 1060 ft (323 m) and with further drilling to 1602 ft (488 m) attained a production of 175 - 240 bbl. per day. Several more exploratory wells were drilled in the area but none encountered oil in any appreciable amount. Following a prolonged period of inactivity, an increased demand in 1939 prompted two more drilling attempts, one of which penetrated to 1215 ft (370 m) and had a production of 100 - 140 bbl. per day. The old

*bbl.: Barrel = 42 gallons = 159 liters

refinery was replaced by an 840 bbl. per day straight-run refinery, later increased to 1200 bbl. per day capacity. Diesel oil and gasoline were produced, mainly for supplying nearby mining operations.

The desirability of developing the Norman Wells field as a defense measure had been advocated as early as 1940 by the well-known Arctic explorer, Dr. Vilhjalmur Stefansson, serving as a special consultant to the War and Navy Departments on cold weather and Arctic problems (Finnie, 1959). No action on the development of Norman Wells or the proposed construction of a highway to Alaska was taken until early in 1942 when the early stages of the conflict with Japan rapidly revealed the exposed position of Alaska. With the decision to construct the Alcan Highway in February 1942, the matter of supplying the installations in Alaska and along the highway with fuel became particularly critical.

On April 29, 1942, after a conference between representatives of the War Department, Standard Oil and Imperial Oil, a decision was made to: (1) boost production at Norman Wells to 3000 bbl. per day by drilling at least nine new wells by September 1942, (2) build a 500 mile (800 km) long pipeline from Norman Wells to Whitehorse by September 15, 1942 and, (3) erect a refinery at Whitehorse capable of handling 3000 bbl. per day by October 1, 1942 (Dod, 1966). The completion dates proved to be far from realistic and the undertaking even more difficult than originally assumed.

The project was assigned to the U. S. Army Corps of Engineers on May 5, 1942 under Col. T. Wyman. J. Gordon Turnbull of Cleveland and Sverdrup and Parcel of St. Louis were selected to be architect-engineers. A cost-plus-a-fixed-fee contract for the construction was awarded on May 20, 1942 to Bechtel-Price-Callahan and six of their associates. The prime contract called for the construction of the crude oil line, designated Canol No. 1 and a refinery. Eventually several major supplements to the contract were added and carried out including the addition of another 1000 miles (1609 km) of pipeline. The Imperial Oil Co. was responsible for the production of oil at Norman Wells while Standard Oil of Alaska was to operate the pipeline and refinery.

Construction

To expedite the flow of men and materials, the War Department activated Task Force 2600 consisting of 2500 men. It included the 388th Engineer Battalion, the 89th and 90th Engineer Heavy Pontoon Battalions along with signal, quartermaster, finance and medical units. Their first task was to assist in the shipment of thousands of tons of supplies and equipment from Edmonton, Alberta to Norman Wells during the summer of 1942. Without this shipment the proposed increase in oil production at Norman Wells to 3000 bbl. per day could not be realized.

The journey started by rail at Edmonton and continued for 285 miles (459 km) to Waterways, where the freight was transferred to barges and boats for movement down the Athabaska and Slave Rivers. Figure 1 shows

the project routes. Navigation on the Slave River was interrupted by 16 miles (26 km) of rapids with a drop of over 100 ft (30 m). At Ft. Fitzgerald everything including barges had to be lifted out of the water and portaged by tractor towed trailers. The barges were launched and reloaded at Ft. Smith where the journey continued; down the Slave River, across the Great Slave Lake (fifth largest lake on the continent at 12,000 square miles) and finally down the Mackenzie River to Norman Wells and the Camp Canol site on the west side of the river, for a total distance of 1420 miles (2285 km). Before the project was completed, 60-70,000 tons of freight were shipped down the rivers, which were navigable about five months each year.

In an effort to keep supplies moving to Norman Wells after the freezeup of the rivers, two winter roads were constructed in the winter of 1942. One extended from Peace River northwest of Edmonton to Ft. Providence, then along the eastside of the Mackenzie Valley to Norman Wells. It was completed in Feb. 1943. The second road started at Ft. Nelson on the Alaska Highway and followed the Liard River to Ft. Simpson on the Mackenzie River. Both routes were temporary, essentially winter trails and passable only when the ground was frozen and ice was on the rivers. Nine thousand tons of freight were hauled over these routes up until the middle of April 1943 when the thaw once again reopened navigation of the water routes.

Fourteen air strips were constructed along the 1200 mile (1931 km) water route from Edmonton to Norman Wells. These fields enabled transport planes to supplement the river transportation for the movement of high priority freight and personnel.

Late in 1942 supplies and equipment, which included parts from a dismantled refinery in Corpus Christi, Texas, were shipped on barges from Prince Rupert and Port Edward on the British Columbia Coast up the 500 miles (805 km) Inside Passage to Skagway. From Skagway they were shipped by rail 110 miles (177 km) over a narrow-gage track which climbed nearly 3000 ft (915 m) over the White Pass to Whitehorse.

Criticism as to the advisability of the venture existed from the beginning and continued throughout the life of the project. Secretary of State Ickes considered the project impractical, as did many others. President Roosevelt remained strongly in favor of Canol although he recognized the project was not commercially feasible (Dod, 1966). With the Japanese attack on Dutch Harbor on June 3, 1942, all doubts were temporarily dispelled.

By mid-June it was apparent that Canol could not possibly be finished by the end of the year and a more expeditious means of getting fuel to Alaska was needed. It was decided to ship fuel by barge from Prince Rupert to Skagway and to lay a pipeline along the 110 mile (177 km) railroad from Skagway to Whitehorse. After completion of the refinery at Whitehorse the fuel produced from Norman Wells crude could be pumped from Whitehorse to Skagway for shipment elsewhere.

Work on Canol No. 2, as this line was called, began in August 1942 and was completed by January 1943. Four-inch pipe was used on this line. At Skagway a pump station and a tank farm were built. At Whitehorse a tank farm with a storage capacity of 240,000 bbl. was built; later additional tanks provided for storage of another 390,000 bbl. of crude oil and finished product.

By late 1942 consideration was being given to the possibility of using Alaska as a springboard for an attack on Japan. A decision was made to lay another pipeline from Whitehorse to Fairbanks along the nearly completed Alcan Highway and to increase the production of Norman Wells crude to 20,000 bbl. per day. Ultimately the fuel could be shipped down the Yukon River to the Bering Sea. This line was designated Canol No. 4 and construction began in March 1943. It was 603 miles (970 km) in length and consisted of 15 pump stations. It was operational by November 1943. A profile of this line is shown in Figure 2. Schedule-40, nominal 3-inch (76 mm), carbon steel, buttwelded, line pipe was employed throughout. Based on a minimum yield strength of 30,000 psi (207 MPa) and a minimum tensile strength of 50,000 psi (345 MPa) as per API Std. 5L, the nominal minimum bursting pressure was calculated as (Corps Engr., 1958):

$$P = \frac{2\ ST}{d} \quad \text{where:}$$

P = Bursting pressure in pounds per sq. inch.

S = Yield strength in pounds per sq. inch.

T = Wall thickness in inches.

d = Inside diameter in inches.

$$P = \frac{2 \times 30{,}000 \times 0.216}{3.068} = 4224 \text{ psi } (29.1 \text{ MPa})$$

Although the line followed the route of the Alcan Highway, construction was not simple. There were 101 water crossings. Permanent bridges carried the line over major crossings but over smaller streams the pipe was laid on stream bottoms or carried on A-frames or cable suspension bridges. Problems with ice and flooding prevailed along the route.

In conjunction with Canol No. 4, one other line was started in October 1942 and was designed to distribute fuel from Whitehorse to Watson Lake along the Alcan Highway, a distance of 267 miles (430 km). This line was designated Canol No. 3. It consisted of 4 pump stations, a pump station and tank farm at Watson Lake and connected with the Skagway-Whitehorse line at Carcross. It was completed in May 1943. A profile of this line is shown in Figure 3.

Schedule-40, nominal 2-inch (51-mm), carbon steel pipe with either threaded or welded ends was employed on this line. It is interesting to note that laboratory tests conducted on samples from this line in 1958 revealed very little corrosion had attacked the pipe and the mechanical properties were (Corps Engr. 1958):

Ultimate strength: 59000 psi (407 MPa)

Yield point as determined by 0.2% offset method: 45000 psi (310 MPa)

Calculated bursting pressure based on

$$P = \frac{2\ ST}{d} = 6400 \text{ psi } (44 \text{ MPa})$$

Building the supplementary pipelines was made relatively easier by the fact that these lines adjoined existing roads or railroads throughout most of their routes. For the construction of the crude oil line from Norman Wells to Whitehorse, there were no roads and for over half the distance, not even a trail. The 600 mile (965 km) proposed route was virtually uninhabited except for two small trading posts. Much of the route, particularly over the mountains of the Mackenzie-Yukon divide, was unexplored. It was across this wilderness that Canol No. 1 had to be laid. The profile for the line is shown in Figure 4.

The first and most difficult task was the construction of a road along the entire route. Reconnaissance and surveying of the proposed route started in June 1942 and continued on through the spring and summer of 1943. Early reconnaissance, particularly over the divide, was conducted from the air. Later surveyors and dog teams were flown in by bush pilots to locate the road. Some of the exploration and surveying from the west side of the divide was done with pack horses.

By Feb. 1943, 1200 Engineering troops started construction of the Canol Road from the Teslin River Crossing of the Alaska Highway, 80 miles (129 km) east of Whitehorse, and simultaneously from three interior points between Teslin and the Mackenzie Mountains. The pioneer road

was completed by late Aug. 1943. By June 1943 the contractor had completed the pipeline from Whitehorse to Teslin and started pipe laying toward the divide.

On the east side of the divide the contractor started road construction from Camp Canol. For the first 50 miles (80 km) where the road traversed the swampy Mackenzie Valley, a new type of construction was tried. All the brush and trees cut from the right of way were piled in the center of the road. Then three foot (0.9 m) deep ditches were excavated along either side of the road to permafrost with the spoils being thrown over the trees to form a foundation for the road fill. Stable material was then hauled in for completing the grade.

Throughout the route the conquering of the wilderness was made even more difficult by the ever present permafrost. Removal of the thin vegetative layer in winter created impassable quagmires during the summer. Constructors soon realized that if the permafrost areas could not be circumvented, the quickest way to build a road over them was by insulating the ground with brush, rock and gravel to retain the frozen state. Then the road was built over this insulator.

By mid August 1943, the Engineer troops were withdrawn and construction was performed exclusively by civilian crews. As the road advanced toward the divide a constant flow of supplies was maintained. Construction of camps, pump stations, telephone lines and the actual laying of the pipeline followed closely behind the road construction.

Ten pump stations were erected 40-50 miles (64-80 km) apart between Camp Canol and Whitehorse plus numerous work camps.

The pumping equipment at each station consisted of three Wilson-Snyder plunger pumps driven by Caterpillar D-13000 engines equipped with crude oil fuel system, thereby permitting operation directly off of the crude line.

The pipeline was laid directly on the surface over the entire route, except for stream crossings. No insulation around the pipe was used since the Norman Wells crude would flow at the lowest expected temperatures. From Norman Wells, the first 458 miles (737 km) of the line was 4-inch pipe with 6-inch pipe used for the remaining 119 miles (191 km) to Whitehorse. Pipe was received in 30-40 foot (9-12 m) lengths with beveled ends ready for welding. The pipe was double jointed to reduce welding time on the line. Crews worked in relays with sled mov[illegible], gasoline engine driven generators. Unprotected welds were made at temperatures down to -50°F (-46°C) (Finnie, 1945).

After stringing the pipe along the ground, the line was supported by side-boom cranes while the joints were tack welded together to form a continuous pipeline. The crane then lowered the sections onto blocks about two feet (0.6 m) high. The final welding crews then completed the welded joints in two passes lying on their back part of the time as the pipe could not be rolled. Often freshly disturbed ground was swampy and the brush was infested with mosquitoes. The welds were then peened or hammered with a hand hammer to relieve the welding stresses. The completed

pipe was then picked up by another side-boom crane and laid on the surface. After a long section of pipe was completed, it was tested with compressed air for leaks.

Little blocking was used under the line and the contraction and expansion were taken care of by the normal winding and weaving of the line over and around humps, hollows, large trees and rocks. Streams were crossed in two ways, either on bridges or trestles or by laying directly on the river bed. Across large rivers, special cast iron mud anchors were installed to hold the pipe against strong currents.

The usual procedure was to weld up the required length of pipe on shore, then pull the pipe across river with cables from the opposite side. Considerable difficulty was encountered crossing the Mackenzie River which is nearly four miles (6.4 km) wide at Norman Wells. Sections were fabricated on a wharf and the leading end was carried on a barge which was pulled across the river by a tug and a hoist located on an island. After laying, examination of the line revealed several bad kinks caused by the current. The damaged sections had to be raised out of the water and replaced by welders working on barges (Richardson, 1944).

The last gap in the Canol Road was closed on New Years Day 1944 across the treeless, windswept expanse of the Macmillan Plateau at an elevation in excess of 5000 ft (1524 m). On Feb. 16, 1944, the tie-in

weld was made on the pipeline, exactly 20 months and 4 days after the first reconnaissance flight across the Mackenzie-Yukon divide (Finnie, 1945). The final pipeline length was 577.3 miles (929.1 km) or about 23 miles (37 km) less than the road distance. The difference was due to a few unplanned deviations of the line from the road during construction.

At Norman Wells drilling continued through the second winter with thirty new wells. Geologists soon realized that this was possibly a major field capable of producing far more than the 3000 bbl./day and there were estimates that one pool alone held a reserve of 35-100 million barrels. Tank farms were constructed at Norman Wells and at Camp Canol besides those at Whitehorse, Skagway, Carcross, Watson Lake, Northway, Tanacross, Big Delta and Fairbanks.

The refinery at Whitehorse was started in April 1943 at a site on the Lewes River. The biggest job in the construction of the refinery was transporting the large components, some weighing over 50 tons, over the narrow-gage railroad from Skagway to Whitehorse. Some of the components barely cleared tunnels and snowsheds along the route. It was necessary to blast out several rocky points along Lake Bennett to get the longer sections, loaded on two cars, around the sharp curves. The 20 mile (32 km) climb to White Pass rose nearly 3000 ft (915 m) before the downward run from Bennett to Whitehorse.

The thermal cracking unit, part of the crude unit and most of the tankage came from a surplus refinery in Corpus Christi, Texas; the boilers from an old power plant at Hamilton, Ontario; and the turbines

and generators from an idle mill in Pinedale, California. Various other parts were picked up from 2000 suppliers throughout the U.S. Eighteen 10,000 bbl. st[illegible] ere erected. By Jan. 1944, the refinery was near completion.

Throughout the construction period, the question concerning the continuation of Canol was hotly debated. By mid 1943 the Japanese had been expelled from the Aleutians and the threat to Alaska had been considerably reduced. There were many who viewed Canol as a visionary and expensive undertaking. The Joint Chiefs declared the completion of the project was necessary to the war effort. A special Senate committee called the Truman Committee investigated Canol in the fall of 1943. It issued a highly critical report charging among other things that the project had been authorized after insufficient study and was continued contrary to the advice of government and industry; however it agreed that the final decision should rest with the War Department. The War Department's decision was to complete the work (Dod, 1966).

On April 16, 1944, the first oil from Norman Wells reached Whitehorse. It had taken two years, some 4000 engineering troops and over 10,000 civilians to complete Canol at a cost of $133,000,000. Despite the controversy, their work was not altogether futile. Although Canol was abandoned after only a year of operation, a great deal had been learned about construction in the far north.

Operation of the Crude Line and Refinery

Upon completion of the crude oil pipeline and refinery at Whitehorse, the Standard Oil Company of California assumed operation of the system as previously agreed upon under Contract No. W-2385-Eng-39. All work was performed under the direction of the Northwest Service Command and actual operations in the field were conducted by the Standard Oil Company of Alaska, a wholly-owned subsidiary of Standard Oil of California. Maintenance of the access roads, operation of the camps and handling of materials and supplies along the road were done by E.W. Elliott as subcontractor. Incidental services were performed under subcontracts to Universal Oil Products, Ethyl Corp. and Bechtel-McCone-Parsons Corp.

In the 331 day period between the first and last deliveries of crude to Whitehorse, April 16, 1944 to March 13, 1945, the line was devoted entirely to transportation of crude to Whitehorse for 319 days. The remaining 12 days were used to deliver gasoline and diesel oil for road construction purposes. During this period an average of 3059 bbl./day were delivered for a total of 975,764 bbl. The desired objective had been set at 3000 bbl./day of crude to Whitehorse. In addition to Whitehorse deliveries, the line handled 50,000 bbl. for station fuel, for construction equipment and for thawing road culverts, etc. Equipment for production of motor gasoline and diesel oil was in operation from May 29, 1944 to April 5, 1945. Equipment for production of aviation gasoline was in operation from Oct 16, 1944 to Feb 28, 1945. Finished products were manufactured in the following quantities (Standard Oil, 1945):

	Total	Avg. per day	Yield from crude
Diesel oil	256,358 bbl	822 bbl.	26.3%
Motor gasoline	351,370	1126	36%
Aviation gasoline	23,459	172	2.4%
Miscellaneous road oil, fuel left in tanks	27,943		2.9%
Fuel used in refinery	207,540 bbl		21.2%
TOTAL	866,670 bbl		88.8%

The total cost of operating the pipelines and refinery was estimated at $4,824,000, which includes $1,320,000 considered properly chargeable to capital cost of the facilities rather than to operating cost. The net amount chargeable to pipelines and refinery operation was $3,504,000. Cost accounts for the operation from Oct. 1944 to Feb. 1945 reveal the following estimates (Standard Oil, 1945):

Stock	Avg. cost/bbl (5-months per.)	Lowest cost/bbl (5-months per)
Crude oil delivered at Whitehorse refinery (Including production costs)	$6.84	$6.27
100 Octane aviation gasoline	$72.42	$54.21
80 Octane motor gasoline	$14.57	$13.11
Diesel oil	$8.49	$7.92

These figures include capital costs incurred by Standard Oil Co. (Alaska) and E.W. Elliott and no allowance was made for plant depreciation.

Looking at actual operating costs, the operating expenses incurred by the Norman Wells-Whitehorse pipeline totaled $1,763,000 with the delivery of 659,130 bbl. crude. The refinery incurred an operating cost of $1,741,000 and produced 659,130 bbl. of product. From these figures the following unit costs can be arrived at:

Pipeline transportation cost	$1.81/bbl.
Refinery manufacturing cost	$2.64/bbl.

The above costs data are not representative of the results obtainable over a more extended period under normal operating conditions. At the time of shutdown in March 1945, the entire operation had not yet reached a point of maximum efficiency, although it was being approached.

Personnel and Labor Conditions

The planned operating and maintenance force was agreed upon as 977 employees, exclusive of 273 employees for road maintenance and related work. During operation the work force varied appreciably from these figures due to the considerable amount of work required for completion of construction and major and minor alterations. At the peak in Nov. 1944, the total force was 1438 employees with more than 450 assigned to non-operational work. Most of the employees were recruited from California, Texas and from Canada after Dec. 1943.

Labor was critical and it was difficult to obtain and hold experienced men. The average turnover rate was 7.1% per month. Nevertheless this was lower than that experienced by the West Coast shipyards and

aircraft industries during the same period. There were many adverse factors which were responsible for the instability of the work force such as crowded living quarters, differential between American and Canadian wage rates, and differentials between operating personnel and construction personnel.

Pipeline Flow

A viscosity of 49 centistokes at -10°F (-23°C) was assumed representative of Norman Wells crude (Fig. 5). Gravity was assumed to be 37.8 deg. API. A chart of theoretical flow rates from Stations 1 and 4, adjusted to 1600 psi pumping pressure is shown in Figure 6. In general, the flow was laminar below -10°F (-23°C) and turbulent above 20°F (-6.5°C), and flow rates were less around 0°F (-18°C) than at -12°F to -15°F (-24.5°C to -26.1°C). The differences between the theoretical and actual flow rates are probably due to the higher gravity of 40 deg. API as compared to the assumed 37.8 deg. API. As a result of weathering*, the gravity of the crude was lower in summer than in winter and decreased about one degree between the Canol tank farm and the Whitehorse refinery. The average API gravity throughout the line between Sept. 1944 - Mar. 1945 was 40.3 deg. API.

During the winter the pipe was generally covered with soft dry snow which served as insulation. Daily variations in pipeline oil temperatures at any station were usually very small, frequently being less than 4°F (2.2°C). The minimum pipeline oil temperature observed was -19°F (-28°C). Laboratory tests had earlier indicated the crude would flow at temperatures as low as -70°F (-57°C).

* A natural refining process.

No unusual difficulties were encountered by sub-zero weather operations; however Norman Wells crude had certain cold-weather characteristics which affected operations. During cold weather, the light fractions, normally volatile at ordinary temperatures, did not weather off and as a result crude used as station fuel had to be artificially weathered to eliminate vapor lock in the fuel system. Also, the wax separated from the crude between 10°F (-12°C) and 0°F (-18°C) which resulted in wax deposition in tanks and lines in the fall but not enough to hamper operations.

Scrapers were run through the entire line during Sep.-Oct. 1944. Accumulations were greatest at the Canol end where lower temperatures prevailed. A 20 ft. (6.1 m) wax plug accumulated by the scraper was removed at Station 2, 12 ft. (3.7 m) at Station 3, 8 ft. (2.4 m) at Station 4, 4 ft. (1.2 m) at Station 5 and plugs were negligible from Station 6 to Whitehorse. Debris of all sorts was also collected by the scraper. The line had to be cut in several places to remove debris and where it had been crushed by construction equipment.

In Nov. 1944 a 60 ft (15.2 m) wax plug was removed in a scraper run from Station 1 to 2. Removal of the plug had no appreciable effect on the pumping rate; however removal of a small amount of wax by scraping this same section in Jan. 1945 resulted in a 13% increase in capacity. Scrapers were not run in any other sections of the line during the winter as there was no evidence of serious loss of capacity.

Air and oil temperatures for each pump station were recorded throughout each day. They clearly showed the effect of variation of oil temperatures from time to time and from place to place. Although oil temperatures at a given location remained fairly constant throughout the winter due to the insulation provided by the snow cover, temperature variations between locations caused the flow in sections of the line to shift from turbulent to laminar or vice-versa, which tended to unbalance the line. In the summer, temperatures varied widely with time and location with a 71°F (39.4°C) variation observed at one station. This resulted in a loss of line capacity due to the expansion and contraction of the oil as well as unbalances resulting from viscosity and volumetric variations.

Due to the combined conditions of terrain, weather, and installation, evidence of line breaks was often difficult to detect. The magnitude of the station pumping pressure drop resulting from a break was a function of the rate of change of line temperature as well as of the size and location of the break. In some cases, existence of a leak was not detected until pump station pumping receipts and withdrawals along the line were carefully checked.

At the time of completion, several features were incomplete including the automatic controls. As a result, initial operation was by manual control. During filling of the line and initial operation, manual control was found necessary anyway because of piping and fitting failures in pump house manifolds, necessity of frequent strainer cleaning,

strainer failures caused by ice deposits, line breaks, and formation of ice plugs. These made it necessary to have operators in constant attendance. By the time the oil arrived at Whitehorse, it was evident that the above factors, together with the great temperature variations with time and location, would preclude the use of automatic controls and they were never used.

Problems

Most of the problems encountered during operation of the line were mechanical ones dealing with the pumps, power plants, valves, etc. Most were relatively minor and could be expected due to the nature of the crude and the environmental extremes. By the end of the operation, most of the problems had been corrected. No serious reduction in throughput was experienced.

Records show that during filling of the line, breaks occurred at 44 locations. During operation, 104 breaks occurred and in addition, damaged pipe was cut out and replaced at 68 locations prior to any breaks. This figure includes relocations on bridges and at other critical points to prevent breaks in streams or to avoid damage by road equipment. Of the 104 failures during operation, about 90% resulted from damage by construction equipment, 5% were failure of mill lap welds, 3% resulted from stresses due to temperature variations and 2% from failure of field welds.

The most significant failure occurred at the Canol tank farm where the wall of an 80,000 bbl. storage tank ruptured on Nov. 13, 1944. The following report is taken from Standard Oil (1945).

"On the morning of Nov. 13, 1944, Tank 410 at Canol tank farm failed by a rupture of the shell that led to complete collapse of the structure. Although the shell was badly broken up, all the fractures took place in the original plate and none followed welds. The tank was an all welded structure of Standard API design, 120 ft (36.6 m) in diameter and 40 ft (12.2 m) high with a nominal capacity of 80,000 bbl. It had been moved, but only the bottom had been welded in the previous location."

"Rupture of the tank and release of its contents of 55,000 bbl. of crude took place so suddenly that the oil surged over the firewalls in a wave several feet high and spilled into the ravines to the east and west of the tank, from where it flowed on into the Mackenzie River. Approximately 20,000 bbl. of oil were retained within the fire wall and will be largely recoverable. The remainder scattered over a large area of sand, brush, and moss cannot be recovered and will present a fire hazard because it will not soak into the frozen ground and weathering will be very slow during the prevailing low temperatures."

"It is the writer's opinion that failure started on the north side of the tank, at a point in the lower edge of the first ring plate where the liquid loading and residual welding stresses were increased up to the elastic limit of the steel by unusual temperature differences and possibly also by non-uniform freezing of the grade. Discontinuity of structure, due to the lapweld between bottom plates, provided a localized area of overstress in a material having high notch-sensitivity and lowered shock resistance strength because of its lowered temperature.

From this condition of incipient failure, a tension crack may have started when the shell was subjected to some minor shock that may have been vibration caused by the incoming oil stream or frost shock in the grade. Once started in a moderately stressed shell this fracture continued and caused complete failure of the structure by progressive impact."

"It is fairly safe to assume that all the unfavorable conditions were necessary to cause failure since the tank had been completely filled several times under difficult weather conditions."

After the spring thaw in 1944, leakage developed in the bottom of the 10,000 bbl. bolted tanks at Canol tank farm. A study of tank losses for the month of June showed losses to be as high as 300 bbl. in 20 days from a single tank.

Leakage from the shells of the tanks was not as severe as bottom leakage. The shells could be readily tightened, but it was necessary to successively empty each bolted tank and perform the following in order to stop bottom leakage: Remove bottom floor plates, either clean existing gaskets or install new gasket material, bolt plates back in place, and apply a coat of Prestite over the seams.

Settlement at Station 7 of the pump house and pumping machinery foundations became so severe by July 1944, that it became necessary to move the camp. The earth around the buildings had been permafrost which had been removed during construction, creating a quagmire during the warm months. The camp was relocated about 3500 ft (1067 m) away on a

rock outcrop. The 5000 bbl. tank at the old station was utilized in conjunction with a new 1500 bbl. tank at the new site.

Shutdown and Disposition

Pumping of crude into Whitehorse stopped on Mar. 13, 1945. Shutdown procedures had already been initiated at the refinery and along the line.

At the end of operations, about 55,000 bbl. of crude were left in the pipeline and 40,000 bbl. in tankage at the Canol tank farm and pump stations. There were also 7118 bbl. of motor gasoline and 2389 bbl. of light diesel fuel in tanks at Canol tank farm. 5375 bbl. of crude were drained out of the pipeline, 5205 bbl. going into tank storage and approximately 170 bbl. on the ground to provide for the thermal expansion in closed sections of the line.

In shutting down the pipeline, each station except Station 1, pumped the equalizing tank down until suction failed, then drained as much as possible of the line contents into the station tank. Station manifolds were drained and the main line was left open to provide for expansion of oil left in the line. Station equipment was protected against rusting and damage by foundation settlement.

Mainline block valves were closed at strategic points to prevent undue spillage in the event of line breaks. Some oil was drained from closed sections of the line to provide room for thermal expansion.

At the refinery all refining units and tanks were emptied of chemicals and hydrocarbon and steam cleaned. All pumps, valves and

instruments were serviced. The power plant, which was the last operating unit, stopped generating power on April 23, 1945. The refinery was eventually dismantled and shipped to Edmonton.

Canol No. 1, the crude line, was never reopened and was eventually removed. The Skagway-Whitehorse line (Canol No. 2) was used to carry imported fuel for several years. It reduced the cost of transporting a bbl of gasoline between these two points from $8.40 to 23 cents (Jacobs, 1976). It was turned over to Canada in 1958. The Whitehorse-Watson Lake line (Canol No. 3) was abandoned after shutdown. The Whitehorse-Fairbanks line (Canol No. 4) carried imported fuel to Fairbanks until 1955 when it was replaced by the Haines-Fairbanks Pipeline. Most of it was taken out of operation and placed in a standby condition (Corps Engr., 1958).

At the Norman Wells Field, by March 1945, 67 wells had been drilled, 60 of which found oil in commercial quantity and seven were classed as dry holes. The drilling outlined an area of more than 4,000 acres, much of which was covered by the Mackenzie River. After Canol was halted, a complete bottom hole pressure survey of the field was made to obtain a more accurate estimate of the recoverable oil reserve. The estimate arrived at was 36,250,000 bbl. from a drainable area of 2,600 acres (10 km^2) (Stewart, 1946).

Conclusions

The Canol Project, although short-lived and highly controversial, was an enormous engineering feat. The total length of pipe laid exceeded

1550 miles (2494 km). Even more difficult were the hundreds of miles of pioneer road that had to be constructed in the virtually uninhabited wilderness. The feasibility of constructing and operating a pipeline in the Arctic was proven, albeit with difficulty and not without numerous problems. Some valuable lessons were learned.

Stripping of the active layer in permafrost areas not only created quagmires during the warmer periods, but also led to foundation settlements which in turn led to storage tank leaks and the relocation of some structures. The ultimate solution was to insulate over the permafrost, then build on the insulation layer which, since then, has become common practice.

The low flow temperature of the crude oil eliminated the need for insulation around the pipe. However, oil temperatures fluctuated considerably with ambient temperatures between locations and caused flow to change from turbulent to laminar and vice-versa, making leak detection extremely difficult and automatic controls useless.

Pipeline breaks were numerous before and after pumping began. However, it is interesting that 90% of the line breaks during operation were due to damage from construction equipment and only 2% due to faulty field welds.

The total output of Canol, some 976,000 bbl., is less than a day's projected flow on the present Alyeska line. The cost of $133,000,000 is minuscule by Alyeska standards. Still, Canol with Alcan must be considered the forerunner of all large scale projects and long-distance piping of oil in the Arctic. The Haines-Fairbanks line several years later relied heavily on the experience of Canol. Probably the most significant contribution made by Canol was that it proved that projects of such magnitude and scope could be realized despite the formidable problems of the harsh Arctic environment.

LITERATURE CITED

Corps of Engineers, Alaska District (1958) Canol Project, Engineering Report, Canol Pipelines No. 3 and 4.

Dod, K.C. (1966) The Corps of Engineers: The War Against Japan. Office of the Chief of Military History, U.S. Army, Washington, D.C.

Finnie, R.S. (1945) Canol: The Sub-Arctic Pipeline and Refinery Project Constructed by Bechet-Price-Callahan for the Corps of Engineers, U.S. Army, 1942-1944. Ryder and Ingram, San Francisco.

Finnie, R.S. (1959) The Evolution of Canol, Polar Notes, No. 1, Nov. 1959.

Jacobs, W.A. (1976) The Alaska District United States Army Corps of Engineers, 1946-1974. Elmendorf Air Force Base, Alaska.

Richardson, H.W. (1944) Controversial Canol, Engr. News Record, Vol. 132, no. 20, May 18.

Standard Oil Co. (1945) Completion Report: Operation of Norman Wells-Whitehorse Pipeline and Whitehorse Refinery. Rept. to Northwest Service Command by Standard Oil Co. of Calif. and Standard Oil Co. (Alaska), May 1945.

Stewart, J.S. (1946) Norman Wells Oil Field. Oil Weekly, March 4, 1946.

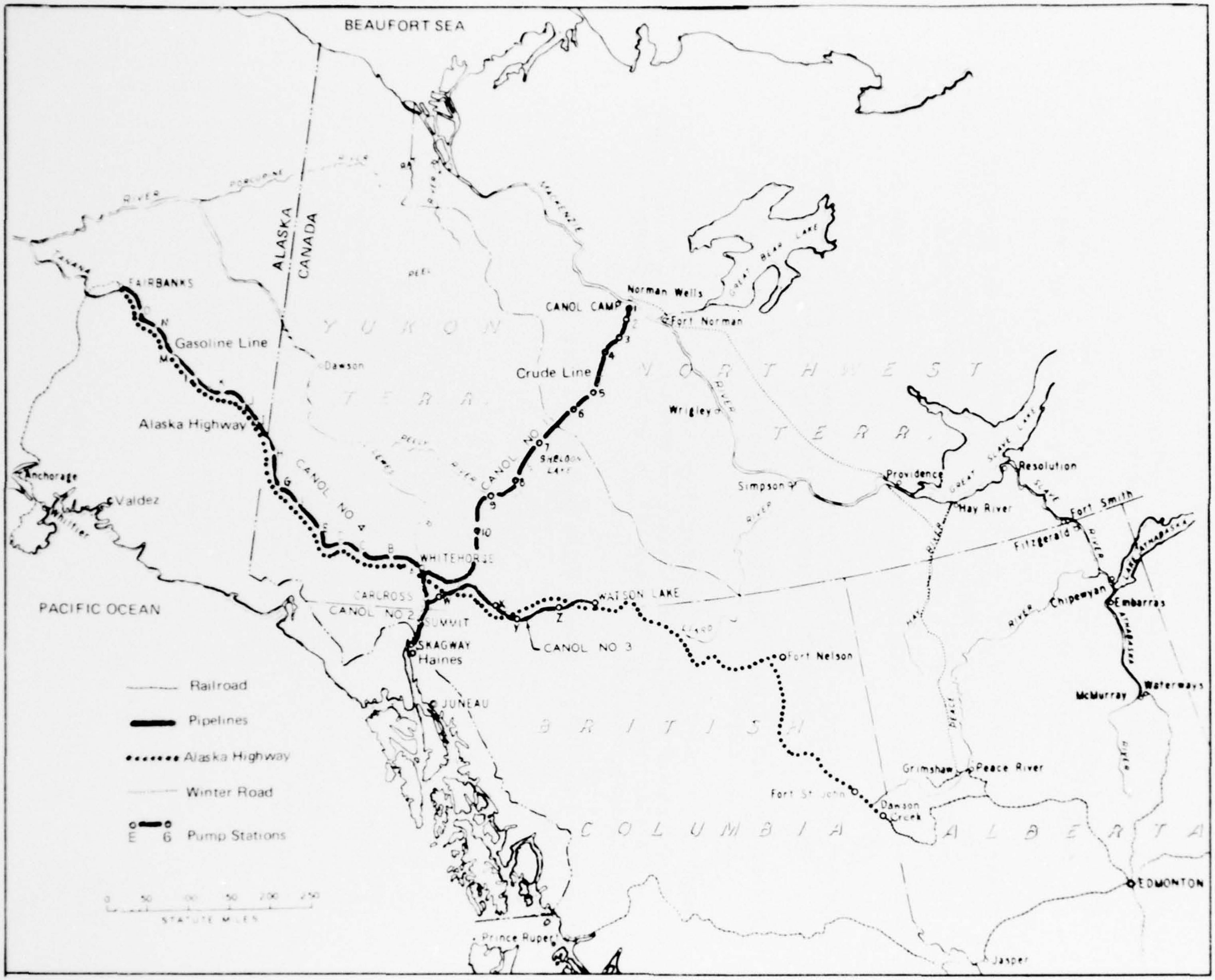

Figure 1. Canol Project

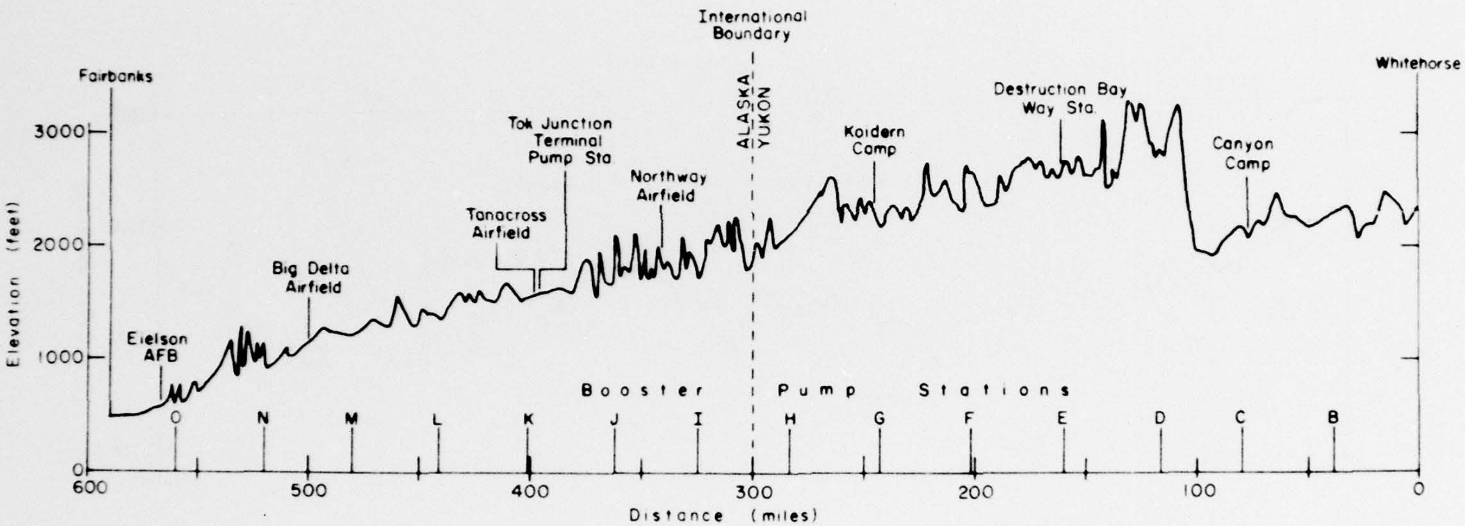

Figure 2. Canol No. 4 Profile (From Corps of Engineers, 1958)

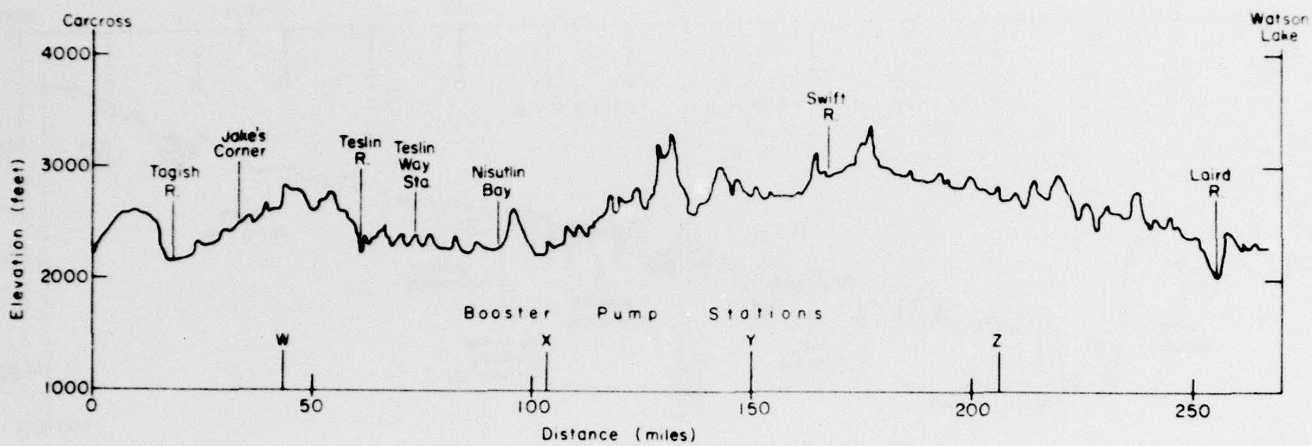

Figure 3. Canol No. 3 Profile (From Corps of Engineers, 1958)

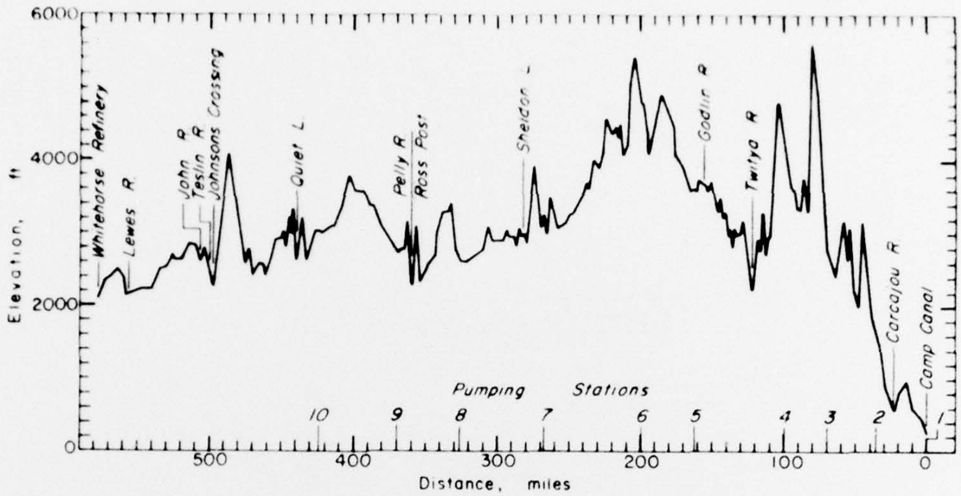

Figure 4. Canol No. 1 Profile (From Standard Oil, 1945)

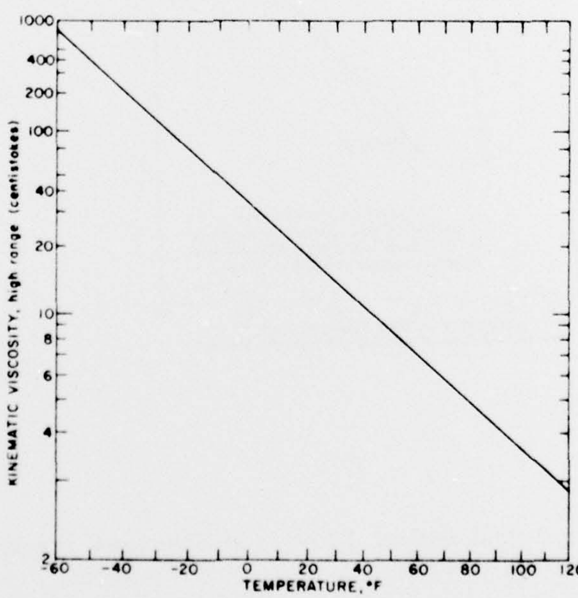

Figure 5. Assumed Viscosity - Temperature Relationship Norman-Wells Crude (From Standard Oil, 1945).

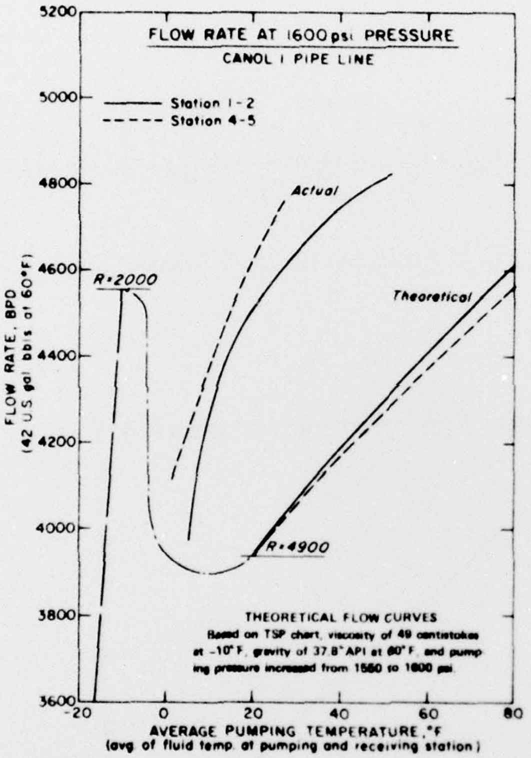

Figure 6. Theoretical and Actual Flow from Stations 1 and 4 (from Standard Oil, 1945).